EFFECT OF ABSORBER PLATE MATERIAL ON FLAT PLATE COLLECTOR EFFICIENCY

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ABSTRACT

The study was conducted to investigate the effect of absorber plate material on the efficiency of heat-absorbing flat plate collectors. Aluminum and copper used in this study because of the heat transfer ability of both materials is high. Absorber plate thicknesses used were 1 millimeter and 2 millimeters which is suitable for the conduction of heat to the working fluid. A model was designed for the experiment. The model was horizontal to the ground during the experiment which conducted from 1000H to 1700H. Inlet and outlet temperature were tabulated into a table with a fix fluid flow rate. Based on the results of the study, 2 millimeters thick aluminum absorber of heat is suitable for use in solar energy collectors. This indicates that aluminum absorber plate is a better absorber of heat in the context of this study. Aluminum is capable of absorbing heat and store heat longer than copper and contributes to high efficiency of the flat plate collector.

ABSTRAK

Kajian dilakukan untuk mengetahui pengaruh bahan penyerap terhadap kecekapan penyerap haba. Aluminium dan tembaga yang digunakan dalam kajian ini kerana kemampuan pemindahan haba dari kedua-dua bahan adalah tinggi. Ketebalam penyerap haba yang digunakan adalah 1 millimeter dan 2 millimeter yang sesuai untuk konduksi panas. Sebuah model dibina sebagai tapak uji. Model tersebut adalah selari dengan aras tapak uji dan kajian dijalankan dari jam 1000 hngga jam 1700. Suhu masuk dan suhu keluar air dicatatkan ke dalam jadual. Berdasarkan hasil kajian, ketebalan 2 mm aluminium penyerap panas sesuai untuk digunakan dalam penyerap tenaga suria. Hal ini menunjukkan aluminium yang merupakan penyerap panas yang baik dalam konteks kajian ini. Aluminium mampu menyerap panas dan menyimpan panas lebih lama dari kuprum dan memberikan nilai kecekapan yang tinggi kepada penyerap tenaga matahari.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Solar energy is the energy that sustains life on earth for all plants, animals and people. It provides a compelling solution for society to meet their needs for clean and abundant sources of energy in the future. Energy has played a key role in bringing about our modern civilization. In the era of modern civilization, energy demands are likely to increase for power generation for industrial and domestic usage.

Solar radiation is primarily transmitted to the earth by electromagnetic waves which strikes Earth's surface every minutes [Foster, R., Ghassemi, M. and Cota, A.; 2010]. Solar radiation provides us with enormous amount of energy. Solar radiation has been utilized for centuries by peoples for heating and drying. Solar water heating is one of the most successful applications of solar energy. Solar collectors for hot water domestic applications are flat plate, evacuated tube, or concentrating collectors.

Flat plate collector (FPC) is a special kind of heat exchanger that transforms solar radiation energy to internal energy which is transferred through a working liquid. FPC is a well known solar collector in the market for water heating application. Simple design, easy to operate and require low maintenance make the FPC commonly found in domestic home.

The principles involve in FPC is to gain as much as possible the radiation energy from the sun by heat absorption. The energy which has been collected is transferred through conduit tubes by working fluids (usually water) which are integrated with heat absorber plate. Then, the warm water carries the heat to the hot water system or to storage subsystem which can be used during low sun radiation [John A. Duffie and William Beckman, 2006].

In FPC, the ability to absorb more energy is most important in its thermal performance. The heat absorber plate serves as the central component of the flat plate collector [A.M Shariah, A. Rousan *et al*, 1999]. When the absorber plate absorbs more heat from the Sun, the outlet temperature (T_{out}) should have higher value from inlet temperature (T_{in}) [P. Rushi Prasad, H.V Byregowda, P.B Gangavati, 2010]. Thus, from the temperature values, efficiency of the FPC can be obtained. For domestic water heating, the FPC can heat the water up to 50°C.

This project is carried out to investigate the efficiency of the FPC with different absorber material and thickness. Analysis will be done to obtain the FPC efficiency between aluminium and copper heat absorber plate with different thicknesses. The understanding of heat transfer and solar thermal are important to make this project run smoothly.

1.2 PROBLEM STATEMENT

The ability of the heat absorber plate to absorb more heat from the sun and maintain the heat is the main key in FPC performance. The efficiency of the FPC is defined as the ratio of the useful gain over some specified time period to the incident solar energy over the same period of time [John A. Duffie and William Beckman, 2006]. Heat absorbed by FPC depends on thermal properties as well as on the design of the heat absorber plate. Material of the heat absorber plate plays a crucial role in the heat absorbing ability due to the thermal properties. Moreover, the correct thickness also important in absorber plate selection. In this project, aluminium and copper are used as the absorber plate. The optimization of thickness and material used in the design of the FPC will yield the desired effect to maximize its efficiency.

1.3 OBJECTIVES

The project is conducted with the following objectives to be achieved:

(i) To design a model of flat plate collector.
(ii) To fabricate a model of flat plate collector as testing model.
(iii) To study the effect of aluminium and copper thickness in flat plate collector efficiency.

1.4 SCOPE OF WORK

The project has to focus on the following scopes in order to achieve the objectives:

(i) Conducting literature review regarding flat plate collector (FPC).

(ii) Investigating the thickness effect of aluminium and copper absorber plate on the flat plate collector (FPC).

(iii) Analyze the data obtained from the testing.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses literature reviews related to flat plate collector efficiency and solar thermal which includes the components such as flat plate collector and absorber plate.

2.2 COMPONENTS OF A FLAT PLATE COLLECTOR

A flat plate collector is a basic and simple heat absorber which absorbs heat from the sun radiation. Flat plate collector as known now was developed by Hottel and Whillier in the 1950s [John A. Duffie and William Beckman, 2006]. Basic flat plate collector in Figure 2.1 consists of few components and their basic function are stated as below [Goswami, D.Y., Kreith, F. and Kreider, J.F.; 1999].

(i) **Glazing cover** – transparent cover typically iron glass which is put on the top of flat plate collector.

(ii) **Glazing frame** – to hold the glazing material.

(iii) **Tubing or fluids pipe** – to facilitate the flow of the working fluid. Water is commonly used as working fluid. Fluid enters at inlet connection and exit at outlet connection.

(iv) **Absorber plate** – to absorb incident solar radiation to gain heat. Then allowing efficient transfer of heat to a working fluid.

(v) **Insulator** – To minimize heat lost from the bottom and sides of the casing.

(vi) **Casing** – A water-proof box surrounds the foregoing components and keeps them free from dust and moisture.

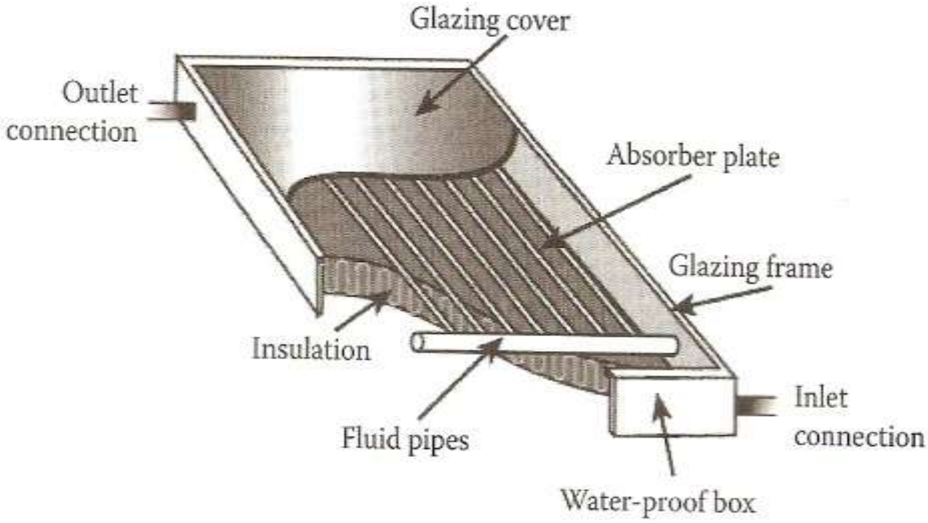

Figure 2.1: Basic component in flat plate collector

Source: John A. Duffie and William Beckman, 2006.

2.3 GLAZING MATERIAL

The purpose of a glazing material is to transmit the shorter wavelength solar radiation and block the longer wavelength reradiating from the absorber plate and reduce the heat loss by convection from the top of the absorber [P. Rushi Prasad, H.V Byregowda, P.B Gangavati, 2010]. Glazing also acts as the cover on the top of the collector casing.

Glass is the most common glazing material because of the low transmittance of the longer wavelength. Glass has the highly desirable property of transmitting as much as 90% of the incoming short-wave radiations while virtually none of the long-wave radiation emitted by the heat absorber plate can escaped outward [P. Rushi Prasad, H.V Byregowda, P.B Gangavati, 2010]. The commercially available window glass will have normal incidence transmittance of about 0.87 to 0.90.

Transparent plastic is also generally used as glazing material in FPC. This plastic poses high short wave transmittance but because most of the plastic properties which cannot stand the ultra-violet radiation for a long time period, transparent plastic is unpopular as glazing material in flat plate collector. Table 2.1 shows transmittance for various glazing material when the direct solar radiation is perpendicular to the glazing material. Crystal clear glass and window glass have highest transmittance of solar radiation. The ability of the glass makes it suitable as heat trap in the collector. Thus, window glass is suitable because it is widely used in local flat plate collector.

Table 2.1: Transmittance of various glazing material.

Material	Transmittance (τ)
• **Crystal glass**	0.91
• **Window glass**	0.85
• **Acrylate, Plexiglass**	0.84
• **Polycarbonate**	0.84
• **Polyester**	0.84
• **Polyamide**	0.80

Source: P. Rushi Prasad, H.V Byregowda, P.B Gangavati, 2010.

2.4 TUBING

There are two types of tubing configuration usually found in flat plate collector [John Canivan, 2009], namely parallel configuration and serpentine configuration.

2.4.1 Parallel configuration

Most flat plate collector has small parallel tubes connected to a larger main carrier pipes as shown in Figure 2.2. These small parallel tubes are called riser tubes because this is where the working fluids would rise in order to harvest the heat from the sun. The parallel tube is designed to transport working fluid from the bottom of the flat plate collector to the top of the flat plate collector. The fluids pressure is higher at the base of the collector and least at the top. If the top and bottom pipes are large, the pressure difference is moderated and the flow rate in each of the parallel pipes is more uniform [John Canivan, 2009]. Unfortunately, the flow rate is minimal at the centre where most of the heat is concentrated. Other problems associated with this configuration are the cost and leaking problems. One small leak can cause catastrophic mess in experimentation and calculation.

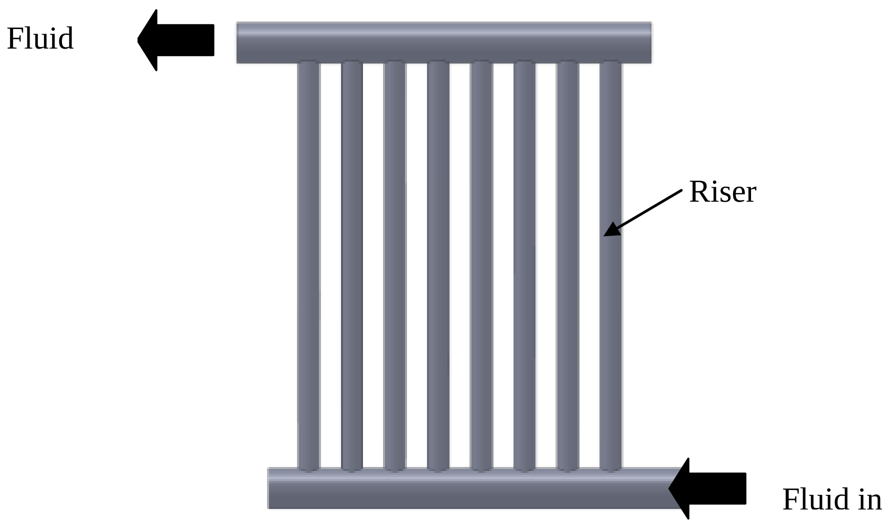

Figure 2.2: Parallel flow configuration.

Source: John Canivan, 2009.

2.4.2 Serpentine configuration

The serpentine flow in Figure 2.3 below consists of one long continuous flexible tube so there is no problem with uniform flow rate. The working fluids flow continuously from bottom to the top of the collector. This results in steady heat transfer from the heat absorber to the working fluid. Since the flow rate of the fluid through the serpentine tube is uniform the heat collection process is uniform. The size of this flexible tubing is an important consideration. The common size used for tubing is 3/8 inches of diameter.

Thus, serpentine configuration is used in this investigation due to uniform fluid flow resulting uniform heat transfer from absorber plate to working fluid. Furthermore, serpentine configuration is easier to construct compare to parallel which have many welding joints. The probability of leaking in parallel configuration is high compare to serpentine configuration. Copper tube is used in this project because it has high thermal conductivity and easy to fabricate [A. Manickavasagan *et al*, 2002].

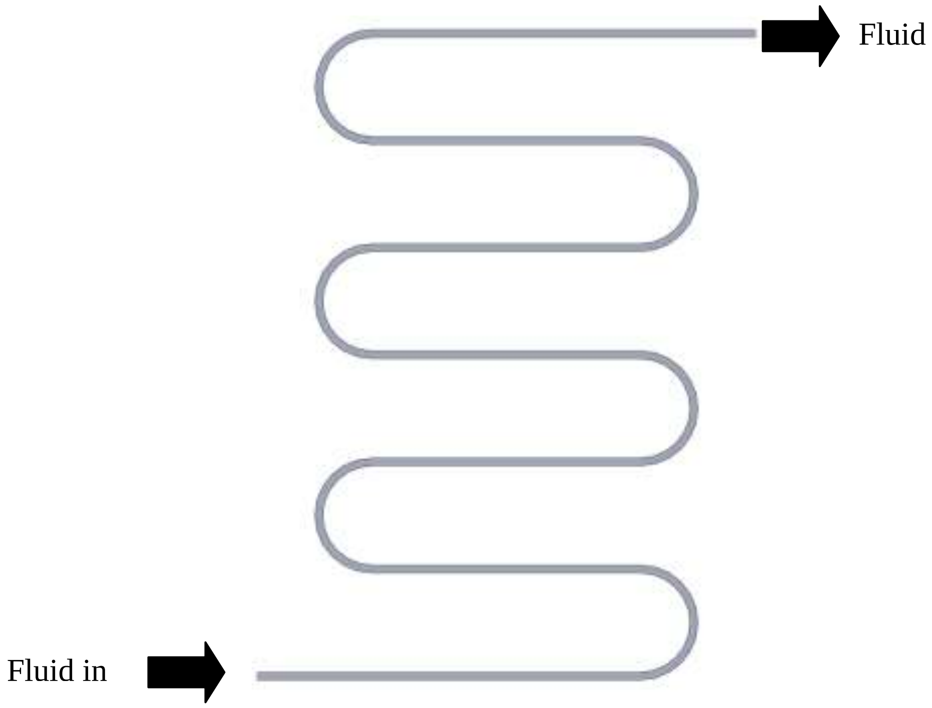

Figure 2.3: Serpentine flow configuration

Source: Source: John Canivan, 2009.

2.5 HEAT ABSORBER

The primary function of the heat absorber plate is to absorbed as much as possible of the radiation reaching through the glazing at the same time to lose as little as possible radiation reflecting upward to the atmosphere and downward through the back of the container later transfer the retained heat to the circulating working fluids [P. Rushi Prasad, H.V Byregowda, P.B Gangavati, 2010].

In FPC, the heat absorber is usually made of copper, aluminium or steel. In this project, aluminium and copper is used for investigation because both of the material have high thermal conductivity. Factors that determine the material selection is its thermal conductivity, its durability, easy handling, cost and availability. Heat absorber plate usually given a surface coating, mainly black, that increases the fraction of available solar radiation absorbed by the plate. Table 2.2 gives value of absorbance of several colours for plate coating. Flat black colour has high absorbance value compare to other colour which make it suitable for heat absorber plate coating. The absorbance (α) for black paint is between 0.92 to 0.98. The black paint is applied by spraying on the plate. Some are heat treated to evaporate solvents and improve adherence. These surface must be able withstand repeated and prolonged exposure to the relatively high temperature.

Table 2.2: Absorbance value for several commonly used colour.

Material colour	Absorbance (α)
White	0.07
Fresh snow	0.13
White enamel	0.35
Green paint	0.50
Red brick	0.55
Grey paint	0.75
Black tar	0.93
Flat black	0.98
Granite	0.55

Source: P. Rushi Prasad, H.V Byregowda, P.B Gangavati, 2010

Flat black colour is used in this project because it has higher radiation absorbance as shown in Table 2.2. The flat black colour minimizes the transmission of outgoing radiation and the FPC can minimize the unwanted reflection. Moreover, material thickness also plays part in heat absorption.

2.6 INSULATOR

FPC must be insulated to reduce conduction and convection heat losses through the back and side of the collector box [D. Yogi Goswani, F. Kreith, J.F. Kredier, 1999]. The insulation material should be dimensionally and chemically stable at high operating temperature. The thickness of the insulator could contribute to the structural rigidity.

This investigation used polystyrene as insulation because it is cheap, easy to find and the most importantly is the polystyrene has good heat insulation characteristic.

2.7 OPERATION FLOW RATE

Suitable flow rate must be used in this investigation. As shown in Figure 2.4, the graph indicated the change in efficiency by varying mass flow rate of the working fluids in the tubes. As mass flow rate increase, the operating temperature decrease resulting higher efficiency [Balbir and Fauziah, 2000]. The suitable flow rate used in this project was set between 0.1 kg/s to 0.14kg/s.

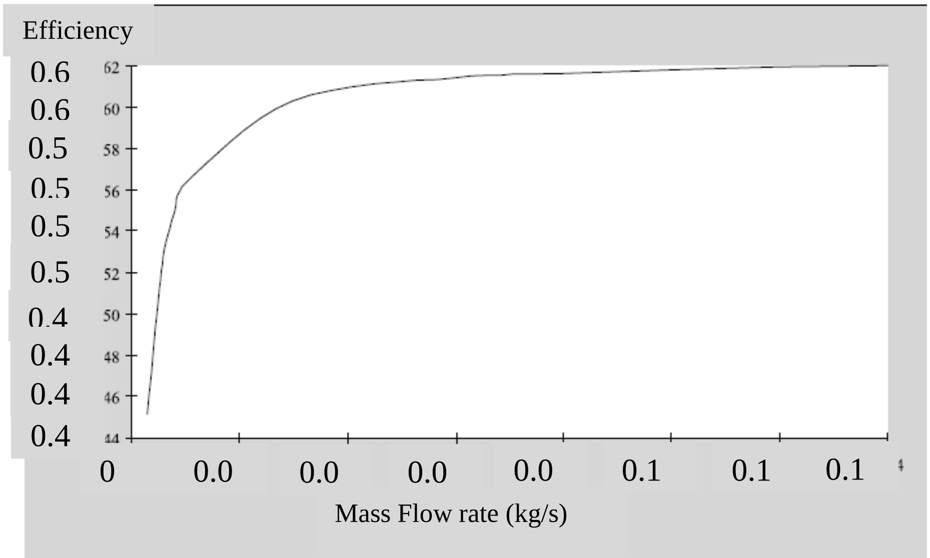

Figure 2.4: Graph of daily efficiency versus mass flow rate for copper plate.

Source: Balbir and Fauziah, Platform 2000.

Working fluids is allowed to flow steady enough to ensure the heat from the absorber plate is transferred uniformly. Temperature difference between the inlet and the outlet are easily measurable when the fluid temperature is already in steady state condition [D.M Ghamari and R.A Worth,1992].

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discusses the flat plate collector experimental setup to run the effect of heat absorber material to the collector efficiency. A model of flat plate collector has been designed and fabricated for experimentation and analysis. A test rig was designed for the FPC to hold the FPC during the experiment.

3.2 DESIGN AND FABRICATION OF FLAT PLATE COLLECTOR

Before the experiment is carried out, a model of FPC had been designed using SOLIDWORK software. Figure 3.1 below shows the FPC that has been designed. Basically, the FPC is rectangular in shape. The FPC is fixed with wheels at the bottom for easy manoeuvre. A handle has been fabricated and attached for handling easiness. Measurement instruments like thermometers and flow meter were fixed at the both side of the handle.

Figure 3.1: Model of FPC in SOLIDWORK.

3.3 FLAT PLATE COLLECTOR SPECIFICATIONS

Table 3.1 below shows the specifications of the FPC for this project. Materials for fabrication process can be easily found in local hardware workshop.

Table 3.1: Specifications of flat plate collector

Component	Unit
Length of collector	812 mm
Wide of collector	508 mm
Thickness of collector	101.6 mm

Copper tube (diameter)	94 mm
Copper tube (thickness)	1 mm
Tube spacing	60 mm
Tube overall length	8229.6 mm
Material of absorber	Aluminium & Copper
Plate thickness	1 mm & 2 mm
Insulator material	Polystyrene
Insulation thickness (bottom)	17 mm
Insulation thickness (side)	13 mm

3.4 LOCATION OF EXPERIMENT

This project was conducted at the Faculty of Mechanical Engineering, Universiti Malaysia Pahang, Kuala Pahang, Pekan, Pahang. The coordinate for the location is 3° 29.542´N; E103° 23.378´E. The location is suitable to run the experiment because the area receives sufficient amount of sun radiation to conduct the experiment. Figure 3.2 shows the satellite image of the location.

Figure 3.2: Satellite image of the location (red marking)

Source: www.google.com/map

3.5 EXPERIMENTAL SETUP

The determination of the flat plate collector efficiency must be done in standard operation. ASHRAE 93-77(2003) method is widely use in testing collector efficiency. The test requires a minimum total solar irradiance of 790 $W/m^{2.}$ The collector is exposed under the Sun while the fluid is circulating under operational flow rate. The collector is set horizontal to the ground.

The principal measurements made in each data set are fluid flow rate, fluids inlet and outlet temperature and solar irradiance. All data are tabulated in a form (Appendix A) for every hour starting from 1000H until 1700H. Data are then plotted in a graph.

Data analysis from the graph is essential to obtain the efficiency of the flat plate collector.

3.6 FLAT PLATE COLLECTOR EFFICIENCY

The efficiency of flat plate collector can be evaluated by an energy that determines the portion of the incoming radiation delivered as useful energy to the working fluids [D. Yogi Goswani, F.Kreith, F. Kreider, 1999]. For flat plate collector, the useful heat gain (Q_u) can be calculated by the formula below.

$$Q_u = mc_p(T_{outlet} - T_{inlet}) \qquad (1)$$

Where:

Q_u : Useful heat gain (Watt)

m : Mass flow rate (kg/s)

c_p : Heat capacity at constant pressure (kJ/kg.K)

T_{outlet} : Fluid outlet temperature (°C)

T_{inlet} : Fluid inlet temperature (°C)

After obtaining the useful heat gain, (Q_u), the efficiency of the flat plate collector can be calculated by using;

$$\eta = \frac{Q_u}{I_t * A_c} \qquad (2)$$

Q_u: enegy absorbed by the flat plate collector (W)

I_t : energy gain from solar radiation $\left({}^{W}/_{m^2}\right)$

A_c : collector absorber area (m^2)

The energy gain from solar radiation can be obtained by reading from a solar meter. This project used ISO-TECH 410 solar meter as shown in Figure 3.1.

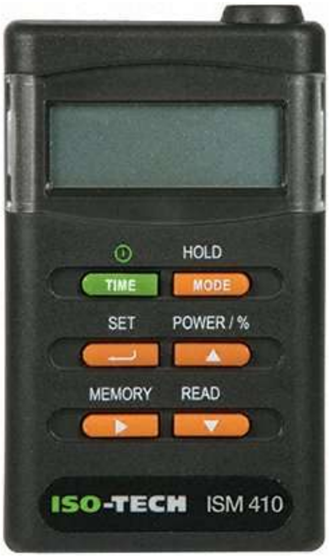

Figure 3.3: ISO-TECH 410 Solar Meter.

Source: www.rs-components.com.my/meter

3.5 FLOW CHART

The project started with literature review on the title. Journals and publication is the main source of this project. The journals mostly found in online library and science portals. After did some findings about FPC and solar water heating, a model was designed for the experiment using computer aided design software. Fabrication process initiated after the design of the FPC undergone several improvements. During the fabrication, several alterations have been done for experiment setup. After fabrication process, the test rig and FPC was ready to be experimented. All the data were tabulated in a table then analyzed to obtain the efficiency of the FPC. From the efficiency graph, the efficiency of FPC for each parameter is known. Finally, a dissertation was written to report the outcome of this project. Figure 3.4 below shows the flow chart about the project.

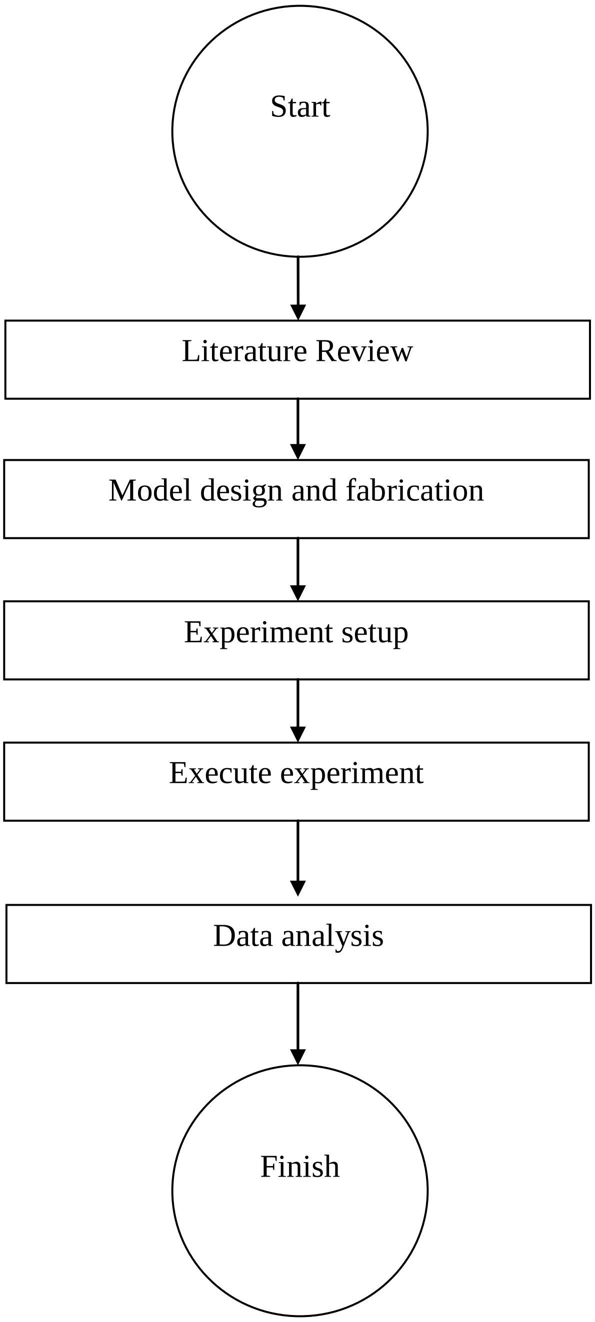

Figure 3.4: Flow chart of the project

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The efficiency of the flat plate collector is determined by the quantity of the sun energy absorb by absorber plate. Outlet temperature and inlet temperature are crucial when determining the heat gain from the sun. The experiment was conducted for each parameter to observe the data accurately. This chapter will analyze and discuss about the effect of thickness of aluminium and copper absorber plate in energy absorption. From there, the efficiency of flat plate collector can be determined. At the end of this chapter, the optimum material and thickness of absorber plate is mentioned.

4.2 HEAT GAIN CALCULATION

Based on Equation (1), the heat gain from the sun for each experiment can be calculated. Heat gain is important for thermal performance analysis of the FPC. It took several days to investigate the effect of absorber thickness on FPC's efficiency. The amount of energy absorbed simply can be calculated from the difference of outlet temperature and inlet temperature. Therefore, outlet temperature is crucial in heat gain calculation.

4.2.1 Aluminium absorber plate.

Figure 4.1 and Figure 4.2 below shows average heat gain for aluminium plate. According to Figure 4.1, data for 1 mm aluminium thickness were tabulated in Table 4.1 until Table 4.4 in Appendix, the outlet temperature during afternoon is varies depending on the sun radiation. Outlet temperature is high especially between 1100H until 1500H. The difference between outlet and inlet temperature during that time is high between that specific times. At 1000H, the absorber plate initiates to absorb heat and because of that the outlet temperature for both days is low. End of the experiment day, the sun already at the west side. The radiation is low which resulting the outlet temperature decreases.

According to Figure 4.2, data for 2mm aluminium thickness were tabulated in Table 4.5 to Table 4.8 in Appendix, the temperature difference is quite significant during afternoon. Sun radiation is optimum during afternoon due to its position which is above the flat plate collector. Figure 4.2 below shows the outlet temperature during afternoon is high especially between 1200H until 1500H resulting the difference between outlet and inlet temperature during that time is high. Thus, the outlet temperature for both days is low. By evening, the sun already at west side therefore the sun radiation is low resulting the decrease of outlet temperature.